

## LCA Case Studies

# Life Cycle Inventory for Electric Energy System in Brazil

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### Abstract

**Goal, Scope and Background.** The goal of this paper is to present the modeling of life cycle inventory (LCI) for electric energy production and delivery in Brazil for the reference year 2000 by application of ISO 14040. Site specific data along with sector production data have been combined to construct an energy production model, which has been applied to emissions estimation. Background-data of all the inputs and outputs from the system have been inventoried as follows: gross electric energy generation, installed nameplate capacity, flooded area, losses, emissions to air / water, process waste, used fuel, efficiency and land use.

**Main Features.** In Brazil, electricity is supplied to the various regions by an interconnected system composed of 418 electric companies, consisting of 389 hydraulic power plants and 29 thermal power stations. Due to this enormous number of companies, life cycle inventory for the electricity grid mix was developed on the basis of the following hierarchy: information received from companies (15), data from Brazilian Industrial Information System for the energy Sector (SIESE) and Brazilian Ministries. The functional unit was 1,000 MJ (278 kWh) of electricity distributed to electricity users. The main emissions from power stations, as well as those from fuel production, were investigated. The hydraulic process was not considered emission-free – a model was proposed where emissions of renewable CO<sub>2</sub> and CH<sub>4</sub> (hydro) are attributed to the degradation of plants submerged in the reservoir areas.

**Result.** The production and distribution of 1,000 MJ of electricity by the interconnected system in Brazil requires approx. 1,600 MJ of process energy, 230 kg of water (evaporated at thermal plants), 116 m<sup>3</sup> of waterflow through the turbines, 13 kg of coal, 5 kg of biotic reserves and 0.25 m<sup>2</sup>a of land use. Emissions related to the 1,000 MJ electricity distributed were 18 kg of non-renewable CO<sub>2</sub>, 17 kg of renewable CO<sub>2</sub>, 540 g of CH<sub>4</sub>, 575 g of NO<sub>x</sub>, 116 g of SO<sub>2</sub>, 149 g of CO, among others. Thermal power stations are the main contributors to these emissions, except for CH<sub>4</sub> and renewable CO<sub>2</sub> being contributions from coal production and hydraulic power plants, respectively.

**Conclusions.** In spite of considering the emissions of CO<sub>2</sub> and CH<sub>4</sub> by the submerged plants in the flooded area of dams in hydropower stations, it has been shown that electric energy production is a very clean process due to the characteristics of the electric energy production in Brazil – 93.5% hydraulic. This means 1,000 MJ of delivered electricity produces approx. 34 kg of CO<sub>2</sub>, being 18 kg (53%) of non-renewable CO<sub>2</sub> emitted by fossil fuel burning at thermal power plants that participate with

only 6.5% of the electric energy production in Brazil. This was the first tentative model to express electric energy generation and distribution in Brazil in terms of LCA. In future, a more detailed study should be made in order to improve this model.

**Outlook.** A complementary paper will be produced in which future scenarios of the Brazilian electricity grid mix will be discussed, including possible alternatives to minimize the environmental impacts of hydropower plants.

**Keywords:** Brazil; electricity; energy; environment; inventory; life cycle assessment (LCA)

### Introduction

The 'life' of a product encompasses everything from raw material extraction (e.g., petroleum, iron ore, wood, etc.) to the disposal of the product after its use. This includes the contribution (in terms of consumption and emissions) of all the transport stages associated with the life of the product and even the generation and delivery processes of the electrical energy utilized, irrespective of the fact whether that electrical energy is grid electricity or obtained by burning fuel in private thermoelectric facilities.

CETEA (the Brazilian Packaging Technology Center) has conducted an LCA study of thirteen identified Brazilian packaging systems from 1997 to 1999 (Madi et al. 1999). This was the first Brazilian project about LCA of packaging systems. Energy production and delivery may contribute a great deal to the environmental impact of certain products, thus an adequate interpretation of this activity in an LCA study is usually crucial (Matsuno et al. 2000, Dubreuil 2001).

Since no LCA has ever been conducted on the electric energy production and delivery in Brazil, this paper presents an application of an LCA model to calculate the environmental burdens of the interconnected electric energy system there (Coltro et al. 2000a and 2000b).

This study has been conducted in accordance with the recommendations of the Society of Environmental Toxicology and Chemistry (SETAC 1993) and International Standard ISO 14040 (1997).

To determine the impact of electric energy production and delivery on the environment, it is necessary to address the different energy conversion processes and basic energy sources that can be used to generate electric energy and which

**Table 1:** Total electric energy generation in Brazil in 2000 (BEN 2002)

Source	Generation (1,000 tep <sup>a</sup> )	Percentage (%)
Hydroelectric	87,404	77.3
Hydroelectric – electric energy received from Itaipu-Paraguay	11,525	11.0
Hydroelectric – electric energy received from independent suppliers (non-utility companies)	1,804	1.6
Total hydroelectric	100,733	89.0
Thermal	7,234	6.4
Thermal – electric energy received from independent suppliers	4,400	3.9
Electric energy received from Argentina	765	0.7
Available energy	113,132	100.0
Total consumption	96,162	–
Industrial consumption	42,288	–
Energy losses (T&D – transmission and distribution)	–16,970	15.0

<sup>a</sup> tep = oil equivalent ton

are generally associated with one of the following processes: hydropower; conventional thermal power; nuclear power; and others (solar energy, wind energy, and so forth).

In Brazil, 99.9% of all electric energy produced comes from the first three energy sources listed above. For that reason, only hydropower, conventional thermal energy and nuclear power were taken into consideration for the purpose of this study. As shown in Table 1, 89% of the total electric energy generated in Brazil in 2000 was produced by conversion of hydropower into hydroelectric power stations.

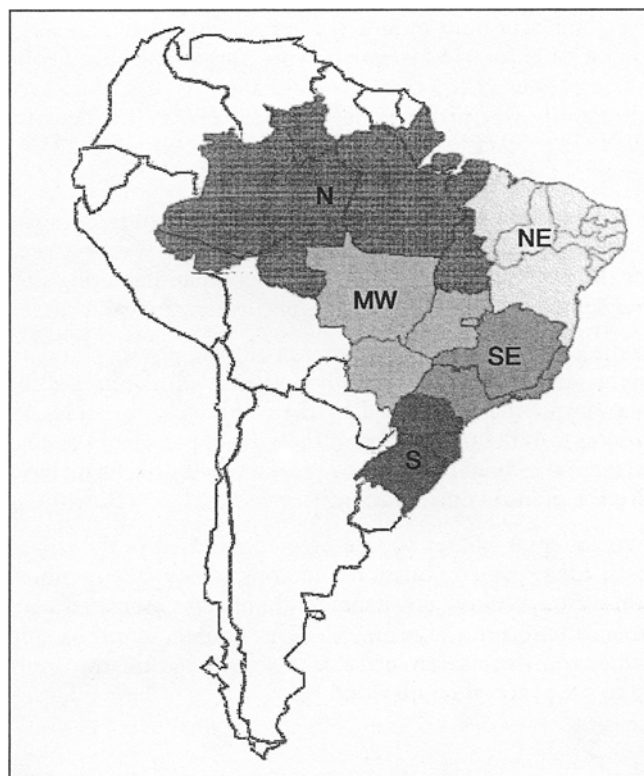
## 1 Goal and Scope

The Goal of this study was to develop an LCI for the interconnected electricity grid mix in Brazil in 2000. The electric energy production and delivery was evaluated in a manner so as to reflect the average situation throughout the Brazilian territory. The study aimed at reflecting, whenever possible, Brazilian resources and technologies relative to the year 2000.

The scope of this work was to trace the average Brazilian situation relative to the production and distribution of the interconnected electric energy system. The functional unit is the production and distribution of 1,000 MJ (1 GJ = 278 kWh) of electric energy.

## 2 Methods

The Brazilian electric energy generation and distribution system is basically composed of two large interconnected subsystems. The first subsystem supplies electricity to the Southern – S, Southeastern – SE and Midwestern – MW regions of the country (where 73% of the consumers live), while the second distributes electric power throughout the Northern – N and Northeastern – NE regions (Fig. 1). In addition to the two main subsystems, there are another more than 300 independent, non-interconnected systems, most of which are located in the Northern and Northeastern portions of the country (representing around 3% of total energy consumption), which were not considered in the scope of this work.

**Fig. 1:** Geographical map of South America, showing Brazil and its regions

The electric power distributed by the two interconnected subsystems is primarily supplied by hydroelectric power stations. Complementary amounts of electricity are supplied by thermal power stations at peak periods that may also be put into operation whenever the demand for electric power reaches critical levels and cannot be covered by the regular production of the hydroelectric stations (Rosa et al. 1998).

The following impact categories were selected for this study: consumption of natural resources; greenhouse effect; acidification; eutrophication; photochemical smog; human toxicity; ecotoxicity; use of dumping grounds for disposal and land use.

The data collection for the model of electric energy production and delivery was carried out on the basis of factors associated with the impact categories selected for the study. Data storage and modeling were performed by means of the PIRA Environmental Management System – PEMS4 software purchased from Pira International.

Initially, the data relative to electric energy generation and distribution in Brazil was collected from the official Internet sites of Brazilian Ministries (BEN 2002). An overview of the electric power generation sector was obtained from the Brazilian Industrial Information System for the Energy Sector (SIESE 2001).

The information from these official sources was submitted to a refining process. For that reason, a letter was sent to 61 electric power stations asking them to supply as much information and data as possible relative to the following items: gross electric energy generation; installed nameplate capacity; reservoir area (hydroelectric power stations); year when the plant was built and/or made fully operational; energy losses; emissions to air/water; types and quantities of solid waste produced (thermal power plants); type of fuel used (thermal power plants); energy efficiency rate of the combustion process (thermal power plants). 15 companies (25%) answered the questionnaire.

It is important to note that the present LCI study does not include capital investments, that is, resources and energy used for the construction and maintenance of manufacturing sites and equipment, roads, power plants, trucks, and so forth.

In the case of conventional thermoelectric power plants, it is not sufficient to include only pollutant emissions and the quantity of fuel consumed by the combustion process. All the stages of the production of fuels, from petroleum or coal extraction to final processing of fuel into a usable form, were also taken into consideration.

Two different phases should be distinguished in the use of fossil fuels: pre-combustion and combustion. Pre-combustion includes all the environmental impacts associated with the extraction of the primary energy source, its processing and/or transformation into a usable form and the transport up to the place of combustion.

### 2.1 Pre-combustion

Partial inventories were prepared relative to the production and processing of petroleum derivatives, such as diesel and fuel oil.

The inventories were elaborated on the basis of information supplied by PETROBRÁS (1998, 1999) – the Brazilian state-owned oil company and emission data published by APME (Boustedt 1993) and EPA (1998). Imported petroleum and petroleum products were dealt with using the data published in the Brazilian Energy Balance (BEN 2002). The contribution of sea transport of the imported fuels was quantified with a transoceanic transport model that is part of the PEMS4 computer program. The PEMS4 model was developed on the basis of data published by IDEA and ETH (IIASA 1991, SFEO 1994).

Detailed data concerning extraction and processing of mineral coal in Brazil were not collected. This issue was addressed only in terms of methane emissions and the yield rates associated with the activities of Brazilian coal mines. The yield rates were obtained by calculating the amount of process waste in producing 1 ton of coal ready for combustion (MCT 2001). Another item considered in this phase was the energy consumed in mining activities in Brazil. The energy consumption was estimated at 10% of the coal lower heat capacity.

### 2.2 Combustion processes

It has proved to be quite an impossible task to obtain reliable data about the combustion of fossil fuels in thermoelectric power stations in Brazil. For that reason, these emissions were estimated on the basis of fuel consumption and any applicable restrictions laid down in the Environment Laws and Regulations currently in force and which stipulate maximum levels for pollutant emissions to the air produced by external combustion processes of fossil fuels (Ventura et al. 1996). For that reason, it was assumed that all these combustion processes take place in thermal power stations using burning technologies and gas treatment systems that keep the emissions within the levels established by applicable Brazilian Laws and Regulations, as described below:

- SO<sub>2</sub>: 2,000 g/10<sup>6</sup> kcal for power stations that have a capacity above 70 MW and 5,000 g/10<sup>6</sup> kcal for generating facilities with a capacity below 70 MW, according to Resolução CONAMA 8/90 (Ventura et al. 1996).
- Particulate matter: 120 g/10<sup>6</sup> kcal for power stations that have a capacity above 70 MW and 350 g/10<sup>6</sup> kcal for generating facilities with a capacity below 70 MW, according to Resolução CONAMA 8/90 (Ventura et al. 1996).
- CO<sub>2</sub> and water vapor emissions, as well as the consumption of air (oxygen and nitrogen) were estimated based on the mass balance of the respective combustion reactions in cases where the exact composition of the fuel (in %) was known. If the exact composition of the fuel was not known, CO<sub>2</sub> emission was calculated on the basis of the carbon emission factors published by IPCC (1996), and taking into consideration the type and lower heat capacity of the fuel.
- CO, NO<sub>x</sub>, N<sub>2</sub>O, CH<sub>4</sub> e NMVOC were estimated on the basis of the emission factors published by IPCC (1996), also taking into account the type and lower heat capacity of the fuel.
- As to the cases in which the sulfur content of the fuel exceeded the maximum level of SO<sub>2</sub> laid down in pertinent legislation, the amounts of sulfur residues retained by gas treatment processes were used to correct the quantities of SO<sub>2</sub> released to the atmosphere.
- Water use in the thermal plants was estimated on the basis of the installed nameplate capacity (MW), production (joules) and evaporated water by technology type (CSPE 2001).

### 2.3 Nuclear thermal power plants

The nuclear power station of Angra consists of three units – Angra 1, 2 and 3 – which operate with pressurized water reactor (PWR). Angra 1 has an installed nominal capacity of 657 MWe (electric MW), Angra 2 has an installed nominal capacity of 1,309 MWe and Angra 3 of 1,245 MWe. However, only Angra 1 and 2 were in operation in 2000. Data of nuclear fuel consumption was obtained from SIESE (2001). Information on emission of radioactivity to the water and to the air were based on non-official data supplied by the Brazilian Institute for Nuclear Energy Research<sup>1</sup>. Any accounting for impacts of nuclear waste was considered. Due to the lack of data, the demand for evaporated water for this Brazilian thermal power technology was based on the ETH database.

### 2.4 Hydropower plants

As for the previously defined impact categories, the hydroelectric power stations were characterized based on the total land area covered by the reservoir waters (land use) and the expected lifetime of the facility. Published literature estimates the average lifetime of a hydroelectric power plant at 100 years (Schreiber 1980). Besides this burden, the following were also considered:

- Water use in the hydroelectric process was estimated on the basis of the waterflow by the long period average (LPA) and by the estimated water volume in the reservoir content (SIPOT 2001).
- Methane and CO<sub>2</sub> were estimated on the basis of the flooded area and the regional emissions (MCT/COPPE

<sup>1</sup> In the case of the radioactive emissions, the authors understand that it is very important to discuss the environmental and social impacts (health etc.) of the nuclear alternative that justify the non-official data employed.

2001), also taking into account the quantity of organic materials submerged/degraded by the water of the reservoir area in hydroelectric power stations (SIPOT 2001).

### 2.5 Imports

Itaipu is an international partnership hydroelectric power plant (Brazil and Paraguay), although Brazil buys (imports) almost 100% of the electricity produced by the 50% Itaipu-Paraguay (SIESE 2001).

The electricity imported from the Argentinian system was modeled in PEMS4 assuming the Brazilian technology database, however, with the Argentina power plant mix (46.6% of thermal power plant burning natural gas, 0.4% diesel, 8.5% nuclear power plant and 44.5% hydropower – Oliva 2002).

## 3 Results and Discussion

As shown in Table 2, 93.5% of all the interconnected electric energy system in Brazil in 2000 was produced by conversion of hydropower in hydroelectric power stations. Fig. 2 presents a flow chart illustrating the global production and distribution process of electric energy in Brazil.

389 hydraulic power plants in operation in 2000 were identified with a total gross electric energy generation of approx. 1,230,773 TJ, installed nameplate capacity of approx. 74 GW and flooded area of approx. 33,992.80 km<sup>2</sup>. An 87% efficiency was calculated due to the turbines, generators and fall (SIPOT 2001).

For the thermal process, 29 power plants were identified having a total gross electric energy generation of approx. 73,878 TJ and installed nameplate capacity of approx. 6 GW. The thermal power plants are basically located in the North and South Regions and operate with diverse fuels (Table 3).

**Table 2:** Interconnected electric energy system in Brazil (TJ) (SIESE 2001)

Source	Generation (TJ)	Percentage (%)
Hydroelectric	1,073,968	81.6
Hydroelectric – electric energy received from Itaipu-Paraguay	146,511	11.1
Electric energy received from independent suppliers <sup>a</sup>	10,295	0.8
Total hydroelectric	1,230,773	93.5
Thermal	73,878	5.7
Electric energy received from Argentina system	11,079	0.8
Available energy	1,315,730	100.0
Total consumption	1,099,291	–
Industrial consumption	471,878	–

<sup>a</sup> considering non-utility companies like hydroelectric power stations

**Table 3:** Thermal power plants in the Brazilian interconnected electric system (SIESE 2001)

Fuel	Number of plants	Installed nameplate capacity (MW)	Fuel consumption		Production		Participation in the interconnected system (%)
			10 <sup>3</sup> ton	kg/GJ	TJ	%	
Fuel oil	11	2,226.8	1,516.0	65.32	23,209	31.4	1.42
Diesel	6	87.9	28.7	92.58	310	0.4	0.03
Coal	9	1,421.0	6,085.0	227.13	26,791	36.3	2.44
Natural gas	1	600.0	160.0	87.91	1,820	2.5	0.14
Uranium	2	1,966.0	0.181	0.01	21,748	29.4	1.65
Total	29	6,301.7	–	–	73,878	100.0	5.68

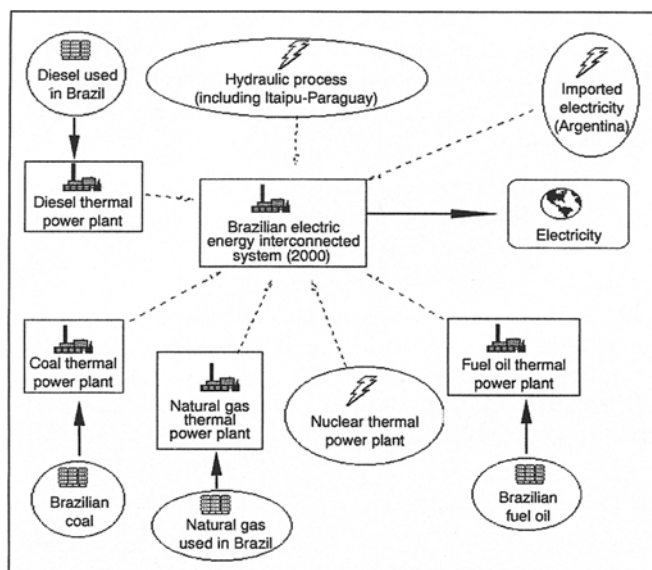


Fig. 2: Schematic diagram of the electric energy generation/importation/distribution network in Brazil (PEMS4)

The data of the partial inventories prepared for hydroelectric and thermal power stations, including the pre-combustion phases, was adapted in accordance with their relative contribution to the Brazilian network of electric power generating facilities, in order to obtain the Inventory of the Electric Energy Generation and Distribution System in 2000, and taking into account the functional unit of 1,000 MJ delivered energy (Table 4). The data was compiled with the PEMS4 software, as shown in Fig. 2, taking into account an energy loss of 15.0% (Table 1).

According to the obtained results, the production and distribution of 1,000 MJ (278 kWh) of Brazilian electric energy requires approx. 1,600 MJ of process energy, 230 kg of water (evaporated in the thermal plants), 116 m<sup>3</sup> of LPA waterflow through the turbines (almost 50% of the reservoir content – 225 m<sup>3</sup>/GJ calculated on the basis of the SIPOT data<sup>2</sup> (2001)), 13 kg of coal, 5 kg of biotic reserves<sup>3</sup> and 0.25 m<sup>2</sup>a of land use. On the other hand, these 1,000 MJ of delivered electricity produces approx. 34 kg of CO<sub>2</sub> – 18 kg (52%) of non-renewable CO<sub>2</sub> emitted by fossil fuel burning at the thermal power plants and 17 kg of renewable CO<sub>2</sub> liberated by the submerged plants at the flooded area of dams in hydropower stations, 540 g of CH<sub>4</sub> – 485 g (90%) of this amount were CH<sub>4</sub> emitted by the degradation of the submerged plants at the flooded area of reservoirs in hydropower plants, 149 g of CO, 116 g of SO<sub>2</sub>, 575 g of NO<sub>x</sub> and 67 g of particulate matter among other emissions as shown in Table 4.

Coal and fuel oil power plants are the main contributors to the non-renewable CO<sub>2</sub> emission, 64.63% and 18.20%, respectively, while electricity imported from Argentina and coal production contributes with 7.07 and 4.49%, respectively,

Table 4: Life Cycle Inventory for 1,000 MJ (1 GJ) of electricity generation and delivery in Brazil in 2000

Parameters	Unit	Quantity / 1 GJ of electricity
<b>Input</b>		
<b>Energy</b>		
Total	MJ	1,584
<b>Natural Resources</b>		
Biotic reserves	kg	4.87
Coal	kg	12.84
Natural gas	kg	0.76
Oil	kg	1.21
Water (Thermal – evaporated)	kg	231.44
Water use (Hydro – LPA flow) <sup>a</sup>	m <sup>3</sup>	116.32
<b>Other Resources</b>		
Minor constituents	kg	0.90
Uranium	g	0.18
<b>Land Use</b>		
Land use	m <sup>2</sup> a	0.25
<b>Output</b>		
<b>Solid Waste</b>		
Landfill volume	dm <sup>3</sup>	13.37
Open loop outputs	kg	0.02
Process waste	kg	10.70
<b>Air Emissions</b>		
Acids (HCl)	g	0.03 x 10 <sup>-3</sup>
CH <sub>4</sub>	g	54.80
CH <sub>4</sub> – Hydro	g	484.75
CO	g	149.39
CO <sub>2</sub> – non-renewable	g	17,832.00
CO <sub>2</sub> – renewable – Hydro	g	16,512.67
Evaporated water (Thermal power plants)	kg	230.35
Hydrocarbons	g	0.75
Metals	g	0.01 x 10 <sup>-3</sup>
NH <sub>3</sub>	g	0.06 x 10 <sup>-4</sup>
NM VOC	g	7.28
NO <sub>x</sub>	g	575.05
N <sub>2</sub> O	g	10.99
Particulate matter	g	67.23
SO <sub>2</sub>	g	116.34
Radioactivity to air	kBq	9.77
<b>Water Emissions</b>		
Acids	g	0.17 x 10 <sup>-3</sup>
BOD	g	0.07
COD	g	0.13
Chlorides	g	0.06 x 10 <sup>-3</sup>
DOC	g	0.05
Heavy metals (Cr, Pb)	g	0.18 x 10 <sup>-3</sup>
Hydrocarbons	g	0.03
Metals	g	0.01
Nitrogen compounds	g	0.45 x 10 <sup>-2</sup>
Oils & greases	g	0.14
Sulfur compounds	g	0.45 x 10 <sup>-3</sup>
TDS	g	0.05
TSS	g	0.10
Radioactivity to water	KBq	15.06

<sup>a</sup> LPA = long period average water flow through the turbine

<sup>2</sup> Maximum and minimum water volumes average, corrected by the hydrographic basin average

<sup>3</sup> Submerged plants in the hydroelectric power stations reservoirs

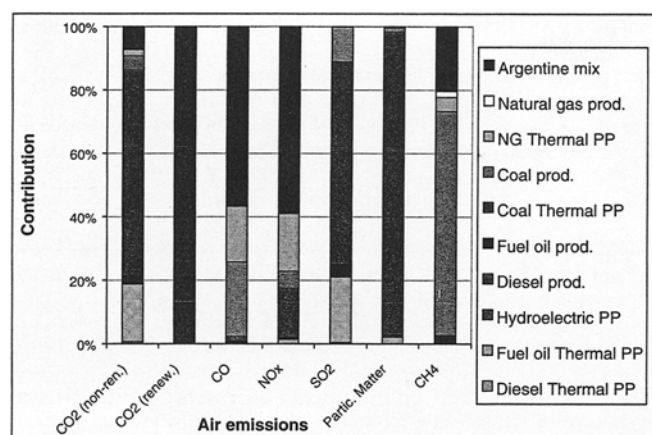


Fig. 3: Contribution of each phase to the main air emissions (prod. = production, PP = power plant)

as shown in Fig. 3. Renewable CO<sub>2</sub> is generated by the hydraulic process. CO emission is mainly due to the imported electricity from Argentina (56.67%), coal production (23.41%) and natural gas power plants (17.64%). NO<sub>x</sub> emission is also a main contribution of Argentinean electricity (58.91%), natural gas power plants (18.33%) and coal power plants (15.42%). SO<sub>2</sub> is an emission attributed mainly to the coal (63.81% from coal power plants and 11.10% from coal production), having a lower contribution of fuel oil power plants (20.64%) and fuel oil production (3.87%). Particulate matter is another contribution associated to the coal power plants (95.47%). CH<sub>4</sub> emission also has coal production as the greater contributor (70.50%), a lower participation of the Argentinean electricity (20.43%) and natural gas power plants (4.45%).

The results showed that besides the low participation of thermal power plants in the Brazilian electrical grid (only 6.5%), these plants are responsible for half of the CO<sub>2</sub> emitted during the electricity generation. Therefore the high percentage of hydro power plants in the Brazilian electric energy grid proves the energy production to be very clean.

#### 4 Conclusions

Methodology for LCI elaboration for electric energy production and delivery in Brazil has demonstrated estimates of the missing emissions dependent on technical parameters of the power plants and fuels.

The LCI presented here represents the interconnected electricity production and was built employing public available databases as well as site specific data.

This was the first tentative model to express electric energy generation and distribution in Brazil in terms of LCA. In this modeling, a method was proposed to consider the CO<sub>2</sub> and CH<sub>4</sub> emitted by the submerged plants in the flooded area of the hydropower stations. In future, a more accurate study should be made in order to improve this model.

Even considering the CO<sub>2</sub> and CH<sub>4</sub> emitted by the decomposition of the plants submerged in the hydropower station dams, it has been shown that energy production and delivery in Brazil is a very clean process due to the characteristics of the electric energy production/distribution – 93.5% hy-

draulic. This means that 1,000 MJ of delivered electricity produces approx. 34 kg of CO<sub>2</sub>, being 18 kg (53%) of non-renewable CO<sub>2</sub> emitted by fossil fuel burning at thermal power plants that participate with only 6.5% of the electric energy production in Brazil.

This feature represents a strong driving force for exportation of Brazilian products.

#### 5 Recommendations and Outlook

LCA is an interesting methodology to construct and analyze alternative scenarios of energy planning. Implications of electric energy production and distribution in Brazil in the performance of Brazilian products as well as future scenarios of the electricity grid mix will be discussed in a future paper that will be submitted to this journal. Another important issue to discuss is the minimization of the environmental impacts that Brazilian hydropower plants have received in the last years by considering aspects such as the use of the biotic reserves previously to the area flooding, biodiversity preservation, etc. (CHESF 2002).

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## Inventory for Energy Production in Canada

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Publicly available databases are analysed to demonstrate their relevance to life cycle inventory for energy production in the Canadian context. Site specific emissions along with sectoral emissions data are combined with production data to construct an energy production model, which has been applied to air emissions. The allocation procedure leads to reasonable results for coal, natural gas and electricity. The detailed allocation of the inventory among petroleum co-products is outside the scope of this study as it requires incorporating knowledge of physical relationship (unit process) or using economic data.

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## Development of Life Cycle Inventories for Electricity Grid Mixes in Japan

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Since most industrial processes consume electricity, it is quite important to develop reliable inventory data for electricity. There is, however, a problem that only a few figures concerning emissions related

to electricity have been reported. In this work, process models of power plants were developed for the Japanese situation which simulate the mass flows and estimate the missing figures of emissions dependent on technical parameters of the plants and fuels. In Japan, electricity is supplied to the various regions by 10 electric companies. Therefore, life cycle inventories for the electricity grid mixes of the 10 electric companies in 1997 were developed. The functional unit is 1 kWh of electricity distributed to electricity users in each region. The emission of CO<sub>2</sub>, SO<sub>2</sub>, NO<sub>x</sub>, CH<sub>4</sub>, CO, non-methane volatile organic compound (NMVOC), dust (all particulates) and heavy metals (Ni, V, As, Cd, Cr, Hg, Pb, Zn) from power stations as well as those from fuel production and transport were investigated. Other pollutants into air, emissions to water, solid wastes, radiation and radioactive emissions from atomic power stations were not included due to a limitation of the available data. Direct CO<sub>2</sub> emissions related to 1 kWh of electricity distributed by companies ranged from 0.21 to 1.0 kg/kWh (average value: 0.38 kg/kWh). Direct emissions of SO<sub>2</sub> and NO<sub>x</sub> from power stations related to 1 kWh of electricity are 2.5\*10<sup>-4</sup> and 2.2\*10<sup>-4</sup> kg/kWh on the average, respectively. SO<sub>2</sub> emissions calculated in this work were somehow large compared with those reported by electric companies. Detailed information concerning total sulfur content in oil consumed in each oil-fired power station are required for an exact calculation of SO<sub>2</sub> emissions from oil-fired power stations. In addition, the ratio of sulfur that goes into slag in combustion must be investigated further. The average amounts of CO, CH<sub>4</sub>, NMVOC and dust emissions were 5.0\*10<sup>-6</sup>, 8.2\*10<sup>-6</sup>, 1.8\*10<sup>-6</sup> and 6.8\*10<sup>-6</sup> kg/kWh, respectively. Heavy metal emissions from power stations were on the order of 10<sup>-9</sup> to 10<sup>-8</sup> kg/kWh. Detailed information concerning heavy metal content in oil and coals consumed in fossil fuel power stations are further required for an improved assessment of heavy metal emissions. Contribution of fuel production and transport to total CO<sub>2</sub> emission was relatively small. On the other hand, contributions of fuel production and transport to total SO<sub>2</sub> and NO<sub>x</sub> emissions were relatively large. In the case of CO, NMVOC and dust, emissions in fuel production and transport were predominant to total emissions. Heavy metal emissions into air during production and transport of fuels were on the order of 10<sup>-6</sup> to 10<sup>-9</sup> kg/kWh.